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Study and Assessment of Dominion's STATCOMs

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SUMMARY

To comply with the Environmental Protection Agency regulations, Dominion Virginia Power has retired and planned to retire large coal plants, reducing a considerable part of generation in its transmission grid. Thus more reactive power support is required and STATCOMs were selected to be the proper compensator. Four STATCOMs distributed in four substations have been deployed in a concentrated area in Dominion transmission grid, providing operational flexibility and redundancy. This paper investigated the operation of the four STATCOMs.

KEYWORDS

STATCOM, control, reactive power compensation, FACTS

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Introduction

In order to have a cleaner and greener generation, Environmental Protection Agency (EPA) regulations have been proposed to reduce the emission of waste. To comply with the regulations, Dominion Virginia Power (DVP) has retired two large coal plants and a third in 2017 in a concentrated area of the Dominion transmission grid. Meanwhile, the load demand in that area is increasing continuously. These two factors result in the requirement of more reactive power support for the future operating plan, since voltage violation has been found under N-1-1 contingencies.

To address the possible operation issue, STATCOMs, as an advanced reactive power compensator, are the type that Dominion is seeking for, due to its flexibility in control and ability to provide reactive power when the system voltages are low. Moreover, four smaller distributed STATCOMs were considered instead of one larger STATCOM, offering operation flexibility and redundancy.

This paper is to investigate and assess the four STATCOMs in proximity to give suggestions of Dominion future operations in the future.

1. Control Structure of A STATCOM

As a voltage source converter (VSC) based converter, the reactive power compensation changes linearly with the system voltage, because its output voltage depends only on its dc bus voltage and modulation of power electronics switches. The main function of a STATCOM is to regulate the system voltage magnitude by injecting or absorbing reactive power. For a conventional controller of STATCOMs, there are three control loops: phase locked loop (PLL), current loop and voltage loop. The PLL is to track the grid voltage, to align the d-axis of the STATCOM's controller with the d-axis of the system voltage. The current loop is to regulate the output current so that over-current protection can be achieved easily. The current loop is typically fast enough, from hundreds of hertz to a thousand hertz in high power applications as in transmission grids, to be ignored in any power system transients. Therefore usually STATCOMs can be considered as a controlled current source since the dynamics from the current loop are neglected.

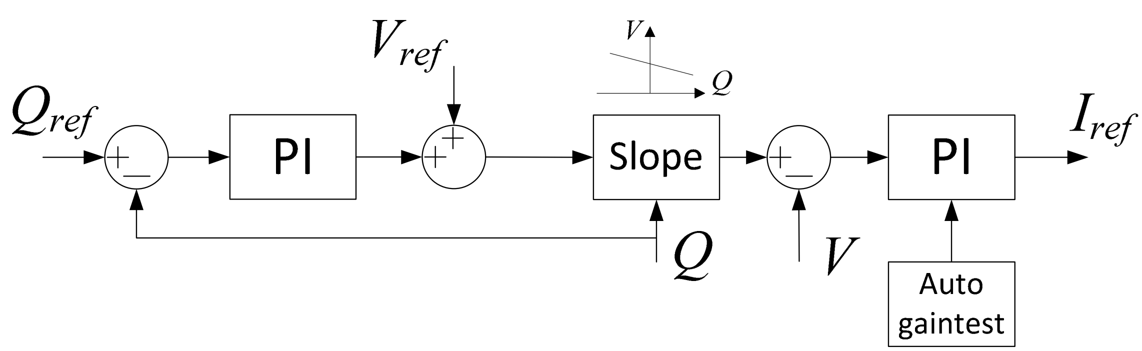

Figure 1 Control block of a STATCOM

The voltage loop is outside the current loop, which is to regulate the ac bus voltage along with the preset Q-V droop, as shown in Figure 1. Depending on the output reactive power, the reference of the ac bus voltage is adjusted according to the Q-V droop and the error between the reference and the actual voltage goes through a proportional-integral (PI) regulator to generate the current reference for the aforementioned current loop.

The uniqueness of this control structure is the fourth loop – reactive power loop (Q loop) which is outside the voltage loop in the left side of Figure 1. The purpose of the Q loop is to regulate the steady-state reactive power to be a certain value, typically about zero, in order to provide the maximum reactive power capability under possible contingencies in sacrifice of voltage deviation. The operation of the Q loop is elaborated in Figure 2. When the system's load characteristics drop, the system voltage will change from the original point V_1 to V_2, regulated by the STATCOM along its Q-V droop with more reactive power output. The Q loop will decrease the voltage reference from V_{ref1} to V_{ref2} to reduce the reactive output to the point V_3. If V_3 is lower than the lower limit, the Q loop will be deactivated and the bus voltage will be at the lower limit.

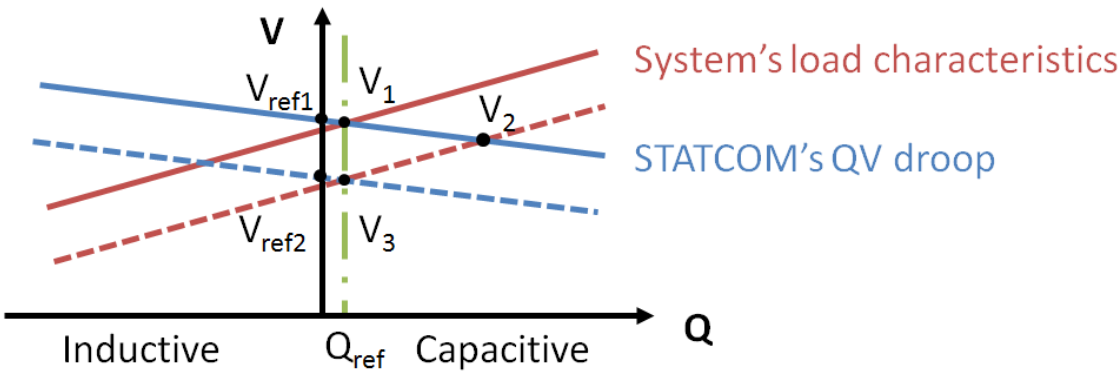

Figure 2 STATCOM's operation

There is also automatic gain adjustment for the voltage loop. If oscillation is detected, it will try to gradually decrease the gain of the PI compensator to damp the oscillation.

2. Assessment of STATCOMs

In this study, the STATCOMs were evaluated with a reduced equivalent network of Dominion transmission grid in PSCAD. The droop slope and the Q loop were assessed and presented in this paper.

A. *Effects of Droop Slope*

The Q-V droop slope is an important setting in the STATCOM's controller, which requires proper setting regarding to the output reactive power and the bus voltage. In the steady-state, the effects are shown in Figure 3 and Figure 4. The system was manipulated in two operating conditions, strong and weak, by tripping some transmission lines and two different slopes, 1% and 2%, were tested. It can be noticed that a steeper slope resulted in less reactive power transferred between each STATCOM and the grid and therefore more voltage deviation from the set points. With a weaker grid, the effects were more significant.

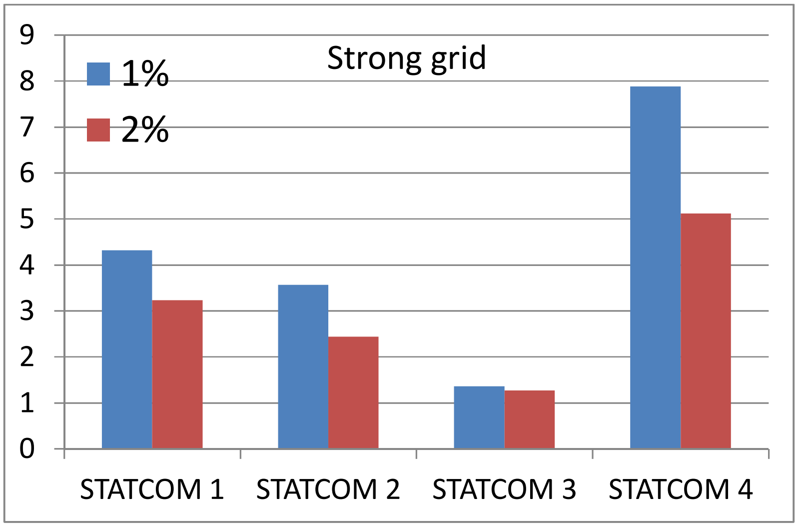

Figure 3 Steady-state reactive power output in MVAR in a strong grid with different slopes

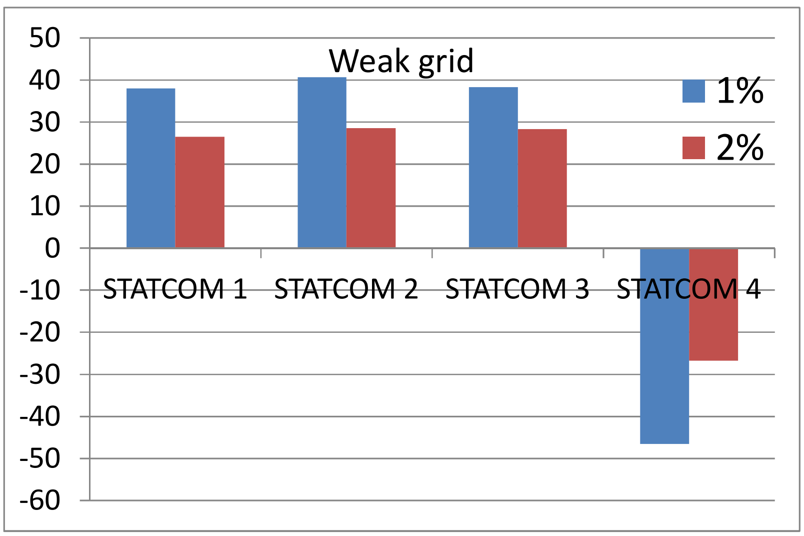

Figure 4 Steady-state reactive power output in MVAR in a weak grid with different slopes

Another aspect of the effect is on the transient responses from N-1 analysis. At the moment of 5 second, a three-phase fault was applied to a remote 500-kV bus and cleared after 0.1 second by tripping the line. The results are shown in Figure 5 and Figure 6 with respect to STATCOM 1. There was an offset between two cases because of different steady-state operation points as seen in the previous study. Although changes in the slope would change the transfer functions of the controller and thus the system eigen-values, there were barely differences in terms of transient responses. It was because the change from 1% to 2% was so small that it could be treated as linear. However the fact that the droop slope does not influence the transient response does not hold when the slope goes steeper since there is no guarantee due to non-linearity.

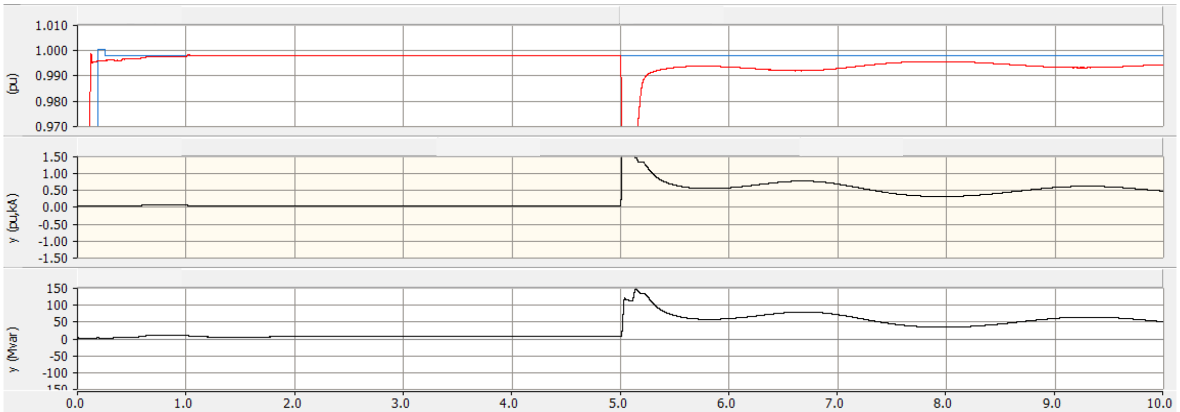

Figure 5 Transient responses of STATCOM 1 in voltage, current and reacitve power with 1% slope

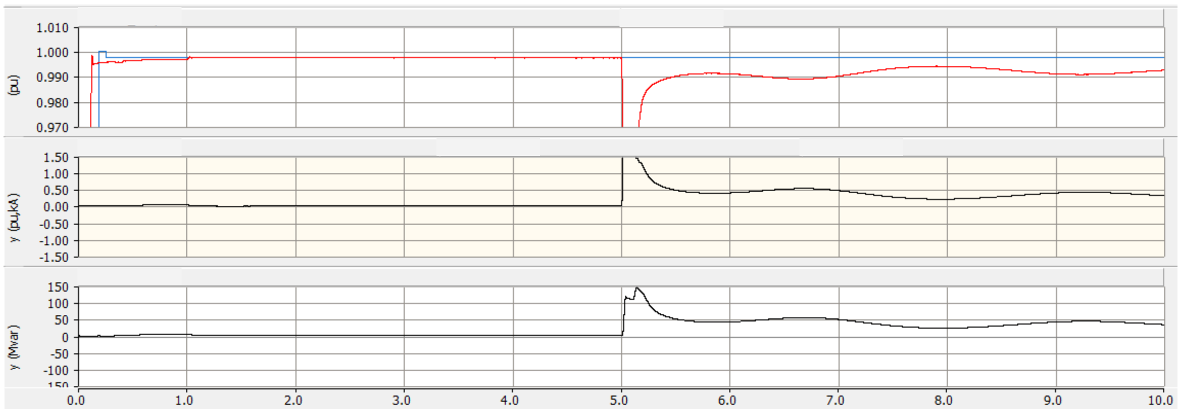

Figure 6 Transient responses of STATCOM 1 in voltage, current and reacitve power with 2% slope

B. Effects of Q Loop

In this section the effects of Q loop is discussed. The same fault from the previous section was applied and cleared in the same manner. The results are shown in Figure 7 and Figure 8 with respect to STATCOM 1. When the Q loop was activated, steady-state oscillation showed up before the moment of 5 second with the magnitude of 13 MVAR in reactive power. It indicated there was interactions between the Q loop and voltage loop and could be resolved by tuning the PI compensators. In the actual implementation and measurement, this oscillation was not found and therefore the PSCAD model was inaccurate. This issue has been reported to the STATCOMs' manufacturer and under review. Also there was a less-damped oscillatory mode after the fault was cleared, which would be investigated further as well.

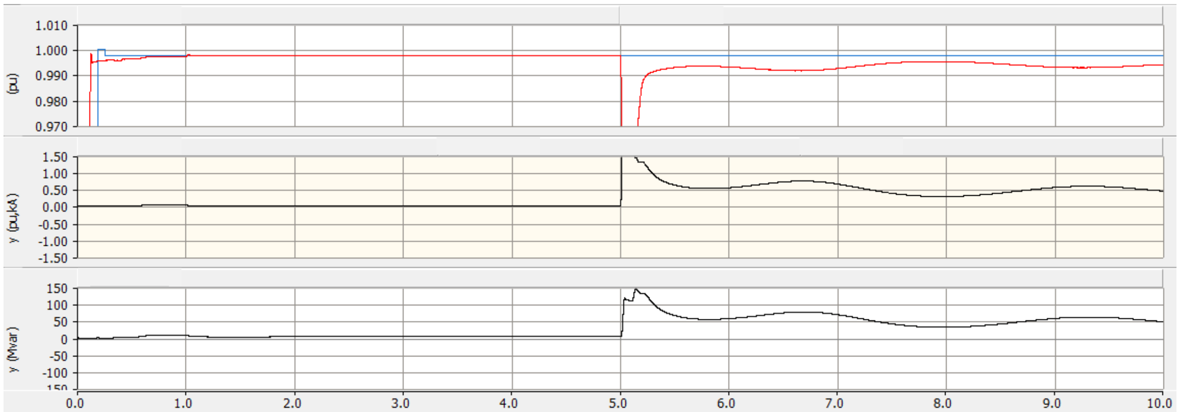

Figure 7 Transient responses of STATCOM 1 in voltage, current and reacitve power with Q loop off

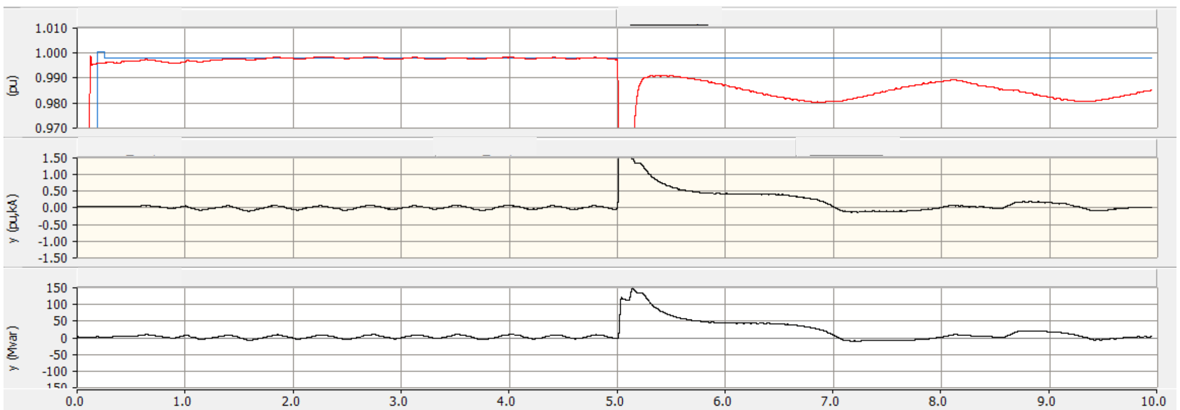

Figure 8 Transient responses of STATCOM 1 in voltage, current and reacitve power with Q loop on

3. Conclusions

To deal with possible voltage violation under future operating conditions due to EPA regulations, Dominion has deployed four STATCOMs in four substations in a concentrated area, providing flexibility and redundancy. Some control settings of the STATCOMs were evaluated. It was shown that the Q-V droop slope had negligible effects on the transient responses but the steeper the slope, the less reactive power transferred between STATCOMs and the grid. The activation of Q loop may result in less-damped oscillatory modes but this seemed to be with issues with the PSCAD model.